



DECLARATION

I, Toshifumi Onuki, c/o TMI ASSOCIATES of 23rd Floor, Roppongi Hills Mori Tower, 6-10-1, Roppongi, Minato-ku, Tokyo 106-6123, Japan, do solemnly and sincerely declare that I well understand the Japanese and English languages and that the attached English version is full, true and faithful translation made by me this 4th day of November 2004 of the certified copy of Japanese Patent Application No. 2000-267286 filed before the Japanese Patent Office on the 4th day of September 2000.

In testimony whereof, I have hereunto set my name and seal this 5th day of November 2004.

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Toshifumi Onuki



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[Inventor]	
10 [Address]	c/o Seiko Epson
[Name]	3-5, Owa 3-chome, Suwa-shi, Nagano Seiichiro HIGASHI
[Inventor]	
15 [Address]	c/o Seiko Epson
[Name]	3-5, Owa 3-chome, Suwa-shi, Nagano Daisuke ABE
[Applicant]	
20 [ID Number]	000002369
[Name]	SEIKO EPSON CORPORATION
[Representative]	Hideaki YASUKAWA
25 [Agent]	
[ID Number]	100093388
[Patent Attorney]	
[Name]	Kisaburo SUZUKI
[Telephone Number]	0266-52-3139
30 [Assigned Agent]	
[ID Number]	100095728
[Patent Attorney]	
[Name]	Masataka KAMIYANAGI
[Assigned Agent]	
35 [ID Number]	100107261
[Patent Attorney]	
[Name]	Osamu SUZAWA
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SPECIFICATIONS

[Title of Invention]

METHOD FOR FABRICATION OF FIELD-EFFECT  
TRANSISTOR

[Claims]

5 [Claim 1] A method for the fabrication of a field-effect transistor comprising the steps of forming a semiconductor layer serving as an active layer on a substrate, and forming a gate insulating film on the semiconductor layer, characterized in that the substrate temperature is set at no higher than 100°C and said gate insulating film is formed.

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[Claim 2] The method for the fabrication of a field-effect transistor according to claim 1, wherein the formation of said gate insulating film being conducted, while heating of said substrate is being prohibited.

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[Claim 3] The method for the fabrication of a field-effect transistor according to claim 1, wherein the formation of said gate insulating film being conducted, while said substrate is being cooled to a temperature of no higher than room temperature.

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[Claim 4] The method for the fabrication of a field-effect transistor according to any one of claims 1 to 3, wherein said gate insulating film being formed by a plasma CVD method.

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[Claim 5] The method for the fabrication of a field-effect transistor according to any one of claims 1 to 3, wherein said gate insulating film being formed by a microwave plasma CVD method.

[Claim 6] A method for the fabrication of a field-effect transistor comprising the steps of forming a semiconductor layer serving as an active layer on a substrate, and forming a gate insulating film on the semiconductor layer, characterized in that the substrate temperature is set at no higher than 100°C and 5 said gate insulating film is formed, and wherein the gate insulating film is heat treated in an atmosphere containing water at a temperature of no less than 100 °C after the formation of said gate insulating film.

[Claim 7] The method for the fabrication of a field-effect transistor 10 according to claim 6, wherein the formation of said gate insulating film being conducted, while heating of said substrate is being prohibited.

[Claim 8] The method for the fabrication of a field-effect transistor according to claim 6, wherein the formation of said gate insulating film being 15 conducted, while said substrate is being cooled to a temperature of no higher than room temperature.

[Claim 9] The method for the fabrication of a field-effect transistor according to any one of claims 6 to 8, wherein said gate insulating film being formed 20 by a plasma CVD method.

[Claim 10] The method for the fabrication of a field-effect transistor according to any one of claims 6 to 8, wherein said gate insulating film being formed by a microwave plasma CVD method.

comprising the steps of forming a semiconductor layer serving as an active layer on  
a substrate, and forming a gate insulating film on the semiconductor layer by the  
two-stage insulating film formation process, characterized in that the substrate  
temperature is set at no higher than 100°C and a first-stage gate insulating film is  
5 formed, and wherein the substrate temperature is set at no less than 100°C and a  
second-stage gate insulating film is formed.

[Claim 12] The method for the fabrication of a field-effect transistor  
according to claim 11, wherein the formation of said first-stage gate insulating film  
10 being conducted, while heating of said substrate is being prohibited.

[Claim 13] The method for the fabrication of a field-effect transistor  
according to claim 11, wherein the formation of said first-stage gate insulating film  
being conducted, while said substrate is being cooled to a temperature of no higher  
15 than room temperature.

[Claim 14] The method for the fabrication of a field-effect transistor  
according to any one of claims 11 to 13, wherein the formation of said first-stage gate  
insulating film being conducted by a plasma CVD method.  
20

[Claim 15] The method for the fabrication of a field-effect transistor  
according to any one of claims 11 to 13, wherein the formation of said first-stage gate  
insulating film being conducted by a microwave plasma CVD method.

25 [Claim 16] The method for the fabrication of a field-effect transistor  
according to any one of claims 11 to 15, wherein the formation of said second-stage

gate insulating film being conducted by a plasma CVD method using TEOS gas.

[Claim 17] A method for the fabrication of a field-effect transistor comprising the steps of forming a semiconductor layer serving as an active layer on 5 a substrate, and forming a gate insulating film on the semiconductor layer by the two-stage insulating film formation process, characterized in that the substrate temperature is set at no higher than 100°C and a first-stage gate insulating film is formed on said semiconductor layer, wherein the substrate temperature is set at no less than 100°C and a second-stage gate insulating film is formed, and wherein the 10 gate insulating films are heat treated in an atmosphere containing water at no less than 100°C after the formation of said gate insulating films.

[Claim 18] The method for the fabrication of a field-effect transistor according to claim 17, wherein the formation of said first-stage gate insulating film 15 being conducted, while said substrate is being controlled to a room temperature.

[Claim 19] The method for the fabrication of a field-effect transistor according to claim 17, wherein the formation of said first-stage gate insulating film being conducted, while said substrate is being cooled to a temperature of no higher 20 than room temperature.

[Claim 20] The method for the fabrication of a field-effect transistor according to any one of claims 17 to 19, wherein the formation of said first-stage gate insulating film being conducted by a plasma CVD method.

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[Claim 21] The method for the fabrication of a field-effect transistor

according to any one of claims 17 to 19, wherein the formation of said first-stage gate insulating film being conducted by a microwave plasma CVD method.

[Claim 22] The method for the fabrication of a field-effect transistor  
5 according to any one of claims 17 to 21, wherein the formation of said second-stage gate insulating film being conducted by a plasma CVD method using TEOS gas.

[Detailed Description of Invention]

[0001]

10 [Field of the Invention]

The present invention relates to a method for the fabrication of thin-film transistors employed as field-effect transistors which are formed on a single-crystal substrate, thin-film transistors formed on an insulator, logic circuits formed therefrom, and a structural component of display drive circuits or display pixels used in electronic apparatuses such as memory circuits, liquid-crystal displays, and organic EL displays.

[0002]

[Related Arts]

20 Semiconductor films such as polycrystalline silicon films have been widely used in thin-film transistors (abbreviated as TFT hereinbelow) or solar cells. In particular, polycrystalline silicon (poly-Si) TFT can be produced on a transparent insulating substrate such as glass substrate, while allowing for increased mobility. Polycrystalline silicon TFTs have been widely used as light modulating elements, for example, in liquid-crystal displays (LCD) or liquid-crystal projectors or as structural elements of internal drivers for liquid-crystal drive and have successfully emerged

into new fields of application, demonstrating there the above-described merits.

[0003]

A fabrication method termed as a high-temperature process has already

5 found application for the manufacture of high-performance TFT on a glass substrate.

The high-temperature process is one of the processes for TFT fabrication, which

uses a high temperature of about 1000 °C. The high-temperature process has

advantages of: allowing for the production of polycrystalline silicon of comparatively

good quality by solid-phase growth of silicon; and allowing for the formation of a

10 good gate insulating film (typically silicon dioxide) and a clean polycrystalline silicon

– gate insulating film interface by thermal oxidation. Those advantages of the

high-temperature process make it possible to fabricate a high-performance TFT

having high mobility and reliability with good stability. However, for a substrate where

a TFT is produced to be suitable for the high-temperature process, it has to

15 withstand high-temperature processing at a temperature of no less than 1000°C.

Presently quartz glass is an appropriate material for transparent substrates satisfying

this requirement. For this reason, the conventional polycrystalline silicon TFT have

been fabricated on small and expensive quartz glass substrates, this process being

cost ineffective and unsuitable for the transition to large-scale structures.

20 Furthermore, since the solid-phase growth method requires long-term heat treatment

(several tens of hours), the productivity is typically very low. Another problem

associated with this method is that the substrate undergoes large thermal

deformations because the entire substrate is subjected to long-term heating. As a

result, inexpensive large glass substrates could not be used. This factor also

25 inhibited cost reduction.

[0004]

By contrast, the technology referred to as a low-temperature process resolves the above-described drawbacks inherent to the high-temperature process and allows for fabrication a high-mobility polycrystalline silicon TFT. The

5 low-temperature process is a process for the fabrication of a polycrystalline silicon TFT in which in order to use comparatively inexpensive heat-resistance glass substrates, the maximum process temperature is set to no less than about 600°C.

Laser crystallization technology in which the crystallization of a silicon film is conducted by using a pulse laser with a very short generation time has been widely

10 used in the low-temperature process. Laser crystallization is a technology employing the capability of an amorphous silicon film located on a glass substrate to be crystallized in a process of solidification after being instantaneously melted by irradiation with a high-power pulse laser beam. In recent years a technology of forming a large-area polycrystalline film by scanning an amorphous silicon film

15 located on a glass substrate with an excimer laser beam, while repeatedly irradiating the film, has found wide application. Furthermore, a silicon dioxide ( $\text{SiO}_2$ ) film can be formed by a film forming method using plasma CVD and the prospects for practical application of this method for growing gate insulating films are promising. The

above-described methods made it possible to fabricate a polycrystalline silicon TFT

20 on a large substrate of several tens of centimeters on a side.

[0005]

However, a problem associated with the low-temperature process is that high-density interface levels appear on the interface between the semiconductor surface serving as an active layer and a gate insulating film (referred to as MOS interface hereinbelow), significantly affecting mobility and the threshold voltage of

TFT. The density of interface levels at a good MOS interface obtained by thermal oxidation at a temperature of no less than 1000°C can be decreased to about  $2 \times 10^{10}$  ( $\text{cm}^{-2}\text{eV}^{-1}$ ), but when the insulating film was grown at a low temperature of no higher than 400°C by plasma CVD and the like, the MOS interface level density was 5 as high as  $10^{11}\sim 10^{12}$  ( $\text{cm}^{-2}\text{eV}^{-1}$ ). Since the energy of those interfaces levels is in the semiconductor band, the carriers can be easily trapped.

In case of a field-effect transistor, if a voltage is applied to a gate electrode, carriers defined by the capacitance of MOS capacitor are induced at the semiconductor side. However, if defects are present at the semiconductor side, that 10 is, at MOS interface, the induced carriers are trapped by the defects and make no contribution to conductivity. As a result, unless a higher gate voltage is applied and more carriers than defects are induced, no drain current can be obtained. This is the reason for increasing the threshold voltage of TFT. At present, there are no effective means for reliably controlling the defects. As a result, the threshold voltage of TFT is 15 high or a large spread is obtained between the lots, which rises serious problems associated with the currently employed manufacturing processes. At present the threshold voltage of polycrystalline silicon TFT manufactured by the low-temperature process is about 3~4 V. If the threshold voltage is increased, for example, to about 1 V, the drive voltage of circuits fabricated by using the TFT can be reduced to less 20 than one third of the present value.

[0006]

Since energy consumed by a circuit is proportional to a second power of the drive voltage, the decrease of the drive voltage to less than one third will make it 25 possible to decrease the energy consumption close to one tenth of the present value. Therefore, it will be possible to produce liquid-crystal displays with an ultralow

energy consumption suitable for displays designed for portable information devices. To attain this object, the surface density of defects in both the poly-Si and the MOS interface should be decreased to about  $10^{10} \text{ cm}^{-2}\text{eV}^{-1}$ .

5 [0007]

[Problems Which the Invention Intends to Solve]

With the foregoing in view, it is an object of the present invention to provide a method for the fabrication of a field-effect transistor which reduces defects at MOS interfaces formed by a low-temperature process and improves characteristics of

10 circuits and polycrystalline silicon TFT.

[0008]

[Means of Solving the Problems]

The above-described object is attained by the present invention described

15 below.

(1) A method for the fabrication of a field-effect transistor comprising the steps of forming a semiconductor layer serving as an active layer on a substrate, and forming a gate insulating film on the semiconductor layer, characterized in that the substrate temperature is set at no higher than  $100^{\circ}\text{C}$  and the gate insulating film is

20 formed.

"Forming a semiconductor layer serving as an active layer on a substrate" as written hereinabove includes a case in which a single-crystal substrate is formed by crystal drawing or the like.

(2) The method for the fabrication of a field-effect transistor according to the above (1), wherein the formation of the gate insulating film being conducted, while heating of the substrate is being prohibited.

- (3) The method for the fabrication of a field-effect transistor according to the above (1), wherein the formation of the gate insulating film being conducted, while the substrate is being cooled to a temperature of no higher than room temperature.
- 5 (4) The method for the fabrication of a field-effect transistor according to any one of the above (1) to (3), wherein the gate insulating film being formed by a plasma CVD method.
- 10 (5) The method for the fabrication of a field-effect transistor according to any one of the above (1) to (3), wherein the gate insulating film being formed by a microwave plasma CVD method.
- 15 (6) A method for the fabrication of a field-effect transistor comprising the steps of forming a semiconductor layer serving as an active layer on a substrate, and forming a gate insulating film on the semiconductor layer, characterized in that the substrate temperature is set at no higher than 100°C and the gate insulating film is formed, and wherein the gate insulating film is heat treated in an atmosphere containing water at a temperature of no less than 100 °C after the formation of the gate insulating film.
- 20 (7) The method for the fabrication of a field-effect transistor according to the above (6), wherein the formation of the gate insulating film being conducted, while heating of the substrate is being prohibited.
- (8) The method for the fabrication of a field-effect transistor according to the above (6), wherein the formation of the gate insulating film being conducted, while the substrate is being cooled to a temperature of no higher than room temperature.
- 25 (9) The method for the fabrication of a field-effect transistor according to any one of the above (6) to (8), wherein the gate insulating film being formed by a

plasma CVD method.

(10) The method for the fabrication of a field-effect transistor according to any one of the above (6) to (8), wherein the gate insulating film being formed by a microwave plasma CVD method.

5 (11) A method for the fabrication of a field-effect transistor comprising the steps of forming a semiconductor layer serving as an active layer on a substrate, and forming a gate insulating film on the semiconductor layer by the two-stage insulating film formation process, characterized in that the substrate temperature is set at no higher than 100°C and a first-stage gate insulating film is formed, and wherein the 10 substrate temperature is set at no less than 100°C and a second-stage gate insulating film is formed.

(12) The method for the fabrication of a field-effect transistor according to the above (11), wherein the formation of the first-stage gate insulating film being conducted, while heating of the substrate is being prohibited.

15

[0009]

(13) The method for the fabrication of a field-effect transistor according to the above (11), wherein the formation of the first-stage gate insulating film being conducted, while the substrate is being cooled to a temperature of no higher than 20 room temperature.

[0010]

(14) The method for the fabrication of a field-effect transistor according to any one of the above (11) to (13), wherein the formation of the first-stage gate 25 insulating film being conducted by a plasma CVD method.

[0011]

(15) The method for the fabrication of a field-effect transistor according to any one of the above (11) to (13), wherein the formation of the first-stage gate insulating film being conducted by a microwave plasma CVD method.

5

[0012]

(16) The method for the fabrication of a field-effect transistor according to any one of the above (11) to (15), wherein the formation of the second-stage gate insulating film being conducted by a plasma CVD method using TEOS gas.

10

[0013]

(17) A method for the fabrication of a field-effect transistor comprising the steps of forming a semiconductor layer serving as an active layer on a substrate, and forming a gate insulating film on the semiconductor layer by the two-stage insulating film formation process, characterized in that the substrate temperature is set at no higher than 100°C and a first-stage gate insulating film is formed on the semiconductor layer, wherein the substrate temperature is set at no less than 100°C and a second-stage gate insulating film is formed, and wherein the gate insulating films are heat treated in an atmosphere containing water at no less than 100°C after the formation of the gate insulating films.

[0014]

(18) The method for the fabrication of a field-effect transistor according to claim 17, wherein the formation of the first-stage gate insulating film being conducted, while the substrate is being controlled to a room temperature.

[0015]

(19) The method for the fabrication of a field-effect transistor according to the above (17), wherein the formation of the first-stage gate insulating film being conducted, while the substrate is being cooled to a temperature of no higher than  
5 room temperature.

[0016]

(20) The method for the fabrication of a field-effect transistor according to any one of the above (17) to (19), wherein the formation of the first-stage gate  
10 insulating film being conducted by a plasma CVD method.

[0017]

(21) The method for the fabrication of a field-effect transistor according to any one of the above (17) to (19), wherein the formation of the first-stage gate  
15 insulating film being conducted by a microwave plasma CVD method.

[0018]

(22) The method for the fabrication of a field-effect transistor according to any one of the above (17) to (21), wherein the formation of the second-stage gate  
20 insulating film being conducted by a plasma CVD method using TEOS gas.

[0019]

[Mode for Carrying out the Invention]

A preferred embodiment of the present invention will be described below with  
25 reference to the drawings attached. FIG. 1 is a cross-sectional view illustrating the process for the fabrication of a polycrystalline silicon TFT.

[0020]

(1. Formation of semiconductor thin film: FIG. 1 (a) )

In order to implement the present invention, usually a protective underlayer 102 is formed on a substrate 101 and then a semiconductor layer 103 is formed  
5 thereon. Accordingly, the formation method consisting of such operations will be described.

[0021]

Examples of substrates 101 suitable in accordance with the present  
10 invention include: conductive materials such as metals; ceramic materials such as silicon carbide (SiC), alumina ( $\text{Al}_2\text{O}_3$ ), aluminum nitride (AlN) and the like; transparent or opaque insulating substances such as fused quartz or glass; semiconductors such as silicon wafers and the like; and LSI substrates obtained by processing the above-mentioned materials. The semiconductor layer is deposited  
15 directly on the substrate or via a protective underlayer or lower electrode. Furthermore, a single-crystal substrate such a silicon wafer can be directly used as semiconductor layer 103 serving as an active layer.

[0022]

An insulating substrate such as silicon oxide film ( $\text{SiO}_x$ :  $0 < x \leq 2$ ) or silicon  
20 nitride film ( $\text{Si}_3\text{N}_x$  :  $0 < x \leq 4$ ) can be used as protective underlayer 102. When a thin-film semiconductor device such as TFT is fabricated on a usual glass substrate, it is important to control the penetration of impurities into the semiconductor layer. In such case, a semiconductor layer is preferably deposited after the formation of the  
25 protective underlayer so as to prevent the penetration of movable ions, for example, of sodium (Na) contained in the glass substrate into the semiconductor layer. The

same extends to cases when various ceramic materials are used for the substrate. The protective underlayer prevents the diffusion and penetration of impurities, for example, from sintering aid raw materials contained in the ceramic, into the semiconductor portion. When it is necessary that a conductive material such as a

5 metal material be used as a substrate and a semiconductor layer be electrically insulated form the metal substrate, the presence of the protective underlayer becomes mandatory for guaranteeing good insulating properties. Furthermore, when a semiconductor film is formed on a semiconductor substrate or an LSI element, the interlayer insulating film present between the transistors or wirings can

10 simultaneously serve as the protective underlayer.

[0023]

The protective underlayer can be formed on a substrate by cleaning the substrate with pure water or an organic solvent such as alcohol and then employing

15 a sputtering method or a CVD method such as atmospheric pressure chemical vapor deposition method (APCVD method), lower-pressure chemical vapor deposition method (LPCVD), or plasma chemical vapor deposition method (PECVD). When a silicon oxide film is used as the protective underlayer, the deposition can be conducted by the atmosphere pressure chemical vapor deposition method by using

20 monosilane ( $\text{SiH}_4$ ) and oxygen as starting materials at a substrate temperature, for example, from about 250°C to about 450°C. In case of plasma chemical vapor deposition or sputtering, the substrate temperature is, for example, within a range from room temperature to about 400°C. The thickness of the protective underlayer should be sufficient to prevent the diffusion and penetration of impurity elements

25 from the substrate. For example, it should be at least no less than about 100 nm. Taking into account the spread between the lots or substrates, the thickness of the

protective underlayer is preferably no less than about 200 nm. If it is about 300 nm, the protective layer functions can be fully demonstrated. When the protective underlayer also serves as an interlayer insulating film between IC elements or wirings connecting them, the thickness is usually within a range from 400 nm to 600  
5 nm. If the thickness of the insulating film is too large, cracks appear which are caused by stresses in the insulating film. For this reason, the maximum thickness is preferably about 2  $\mu$ m. When productivity is an important issue the upper limit of insulating film thickness is at about 1  $\mu$ m.

10 [0024]

Semiconductor layer 103 will be further described. Examples of semiconductor layers suitable in accordance with the present invention, in addition to semiconductor films consisting of a single Group IV element such as silicon (Si) or germanium (Ge), include semiconductor films composed of several Group IV elements such as silicon-germanium ( $Si_xGe_{1-x}$  :  $0 < x < 1$ ), silicon carbide ( $Si_xC_{1-x}$  :  $0 < x < 1$ ), germanium carbide ( $Ge_xC_{1-x}$  :  $0 < x < 1$ ) and the like, complex compound semiconductor films composed of a Group III element and a Group V element such as gallium arsenide (GaAs), indium antimonide (InSb), and the like, complex compound semiconductor films composed of a Group II element and a Group VI element such as cadmium selenide (CdSe) and the like. Furthermore, the present invention is also applicable to complex compound semiconductor films such as silicon-germanium-gallium-arsenic ( $Si_xGe_yGa_zAs_z$  :  $x + y + z = 1$ ), N-type semiconductor films obtained by doping those semiconductor films with a donor element such as phosphorus (P), arsenic (As), antimony (Sb), and the like, and P-type semiconductor films obtained by doping those semiconductor films with an acceptor element such as boron (B), aluminum (Al), gallium (Ga), indium (In), and

the like. Those semiconductor films are formed by a CVD method such as APCVD method, LPCVD method, PECVD method, and the like, or by a PVD method such as sputtering method or vapor deposition method. When a silicon film is used as the semiconductor film, the deposition with the LPCVD method is conducted by using

5 disilane ( $\text{Si}_2\text{H}_6$ ) as a starting material and maintaining the substrate temperature within a range from about 400°C to about 700°C. With the PECVD method, the deposition can be conducted by using monosilane ( $\text{SiH}_4$ ) as a starting material and maintaining the substrate temperature within a range from about 100°C to about

10 500°C. With the sputtering method, the substrate temperature is within a range from room temperature to about 400°C. In the initial (as-deposited) state of the semiconductor film thus deposited, it has an amorphous, primary crystalline, finely crystalline, or polycrystalline structure. In accordance with the present invention, any of such initial states is allowed. Furthermore, in the present specification, the term crystallization covers not only the crystallization of amorphous phase but also

15 recrystallization of polycrystalline or finely crystalline phase. When the semiconductor film is used for a TFT, the appropriate thickness thereof is within a range from about 20 nm to about 100 nm.

[0025]

20 (2. Laser Crystallization of Semiconductor Film: FIG. 1 (b), FIG. 2, FIG. 3)

After the protective underlayer and semiconductor layer have been formed on substrate, the semiconductor layer is crystallized by laser radiation (laser beam 104). The surface of silicon film deposited by a CVD method such as LPCVD method, PECVD method, and the like is often coated with a natural oxidation film.

25 Therefore, this natural oxidation film has to be removed prior to irradiation with laser

beam. For this purpose, for example, a wet etching method is employed in which the film is immersed in a hydrofluoric acid solution, or dry etching is conducted in plasma comprising fluorine.

5 [0026]

Then, the substrate having the semiconductor layer formed thereon is set in a laser irradiation chamber. A part of the laser irradiation chamber is composed of a quartz window and laser beam is irradiated through the quartz window after the chamber has been evacuated.

10

[0027]

The laser beam will be described below. The laser beam is preferably intensely absorbed by the surface of semiconductor layer 103 and practically not absorbed by protective underlayer 102 or substrate 101 located directly thereunder.

15 Therefore, excimer layer, argon ion laser, or YAG laser higher harmonics with a wavelength within ultraviolet range or close thereto are preferred as the laser beam. Furthermore, high-power and ultra-short pulse generation is required to heat the semiconductor thin film to a high temperature and at the same time to prevent damage of substrate. Therefore, excimer lasers such as xenon chloride (XeCl) laser  
20 (wavelength 308 nm) or krypton fluoride (KrF) laser (wavelength 248 nm) are most suitable for laser beam generation. The laser beam irradiation method will be described below with reference to FIG. 2. The intensity half-width of the laser pulse is, for example, an ultra-short time from about 10 ns to about 500 ns. When the temperature of substrate 200 is within a range from about room temperature (for  
25 example, 25°C) to about 400°C, laser irradiation is conducted in vacuum with a background vacuum degree of from about  $10^{-4}$  Torr to about  $10^{-9}$  Torr. The shape of

the surface subjected to a single laser irradiation is a square or a rectangle with a diagonal of from about 5 mm to about 60 mm. The explanation will be conducted hereinbelow with respect to a case using a beam that can crystallize, for example, a 8-mm square area in a single laser irradiation operation. After irradiating one site

5 with a single-pulse laser irradiation in a position 201, the laser beam is shifted at a certain distance 203 in the horizontal direction (X direction) relative to substrate. In this position 202, another single-pulse laser irradiation is conducted. Continuous repetition of such shot-and-scan operations is suitable even for a substrate with a large surface area. The movement distance is from about 1% to about 99% of the

10 irradiated region per each irradiation operation (for example, 50% correspond to 4 mm in the above-described example). Upon completing scanning in the horizontal direction (X direction), the beam is shifted at an appropriate distance 204 in the vertical direction (Y direction) and again scanning is conducted in the horizontal direction (-X direction) with a preset shift amount 203. Then, scanning is repeated to

15 cover the entire substrate surface and complete the first-cycle laser irradiation. The energy density of the first-cycle laser irradiation is preferably within a range from about 50 mJ/cm<sup>2</sup> to about 600 mJ/cm<sup>2</sup>. Once the first-cycle laser irradiation has been completed, a second-cycle laser irradiation is conducted, if necessary, over the entire substrate. When the second-cycle laser irradiation is conducted, the energy

20 density thereof is preferably higher than that of the first-cycle laser irradiation and may be within a range from about 100 mJ/cm<sup>2</sup> to 1000 mJ/cm<sup>2</sup>. Similarly to the first-cycle laser irradiation, scanning is conducted by shifting a rectangular irradiation region at an appropriate distance in the Y direction and X direction. Furthermore, if necessary, a third-cycle or fourth-cycle laser irradiation can also be conducted at a

25 higher energy density. When such multistage laser irradiation method is used, a spread originating at the edges of the laser irradiation region can be completely

eliminated. In each of one-stage irradiation cycles, laser irradiation is conducted at an energy density causing no damage to semiconductor film. In addition to scanning illustrated by FIG. 2, crystallization may also be promoted, for example, as shown in FIG. 3, by providing a line-like shape (301) of the irradiation zone, this shape having

5 a width of about 100  $\mu\text{m}$  and a length of no less than several tens of centimeters and scanning the substrate with the line-like laser beam. In this case, overlapping of beams in the width direction per each irradiation cycle is, for example, from about 5% to about 95% of the beam width. When the beam width is 100  $\mu\text{m}$  and overlapping per beam is 90%, the beam advances 10  $\mu\text{m}$  per one irradiation cycle.

10 Therefore, the same point is subjected to ten laser irradiation cycles. Usually, at least about five laser irradiation cycles are desired to cause uniform crystallization of a semiconductor film over the entire substrate. Therefore, the overlapping of beams per each irradiation cycle is required to be of no less than 80%. In order to obtain reliably a polycrystalline film with a high degree of crystallinity, the overlapping is

15 preferably adjusted to a range from about 90% to about 97% so that one point be irradiated from about 10 times to about 30 times. The merit of the process using a line beam is that crystallization within a wide area is conducted by unidirectional scanning and therefore, a throughput is increased.

20 [0028]

(3. Plasma Treatment of Semiconductor Thin Film)

Defects with a high density of about  $10^{18}$  ( $\text{cm}^{-3}$ ) are present in the polycrystalline silicon film immediately after laser crystallization. This is because laser crystallization is a very fast crystal growth process, and an especially large

25 number of defects are localized at crystal grain boundaries. Those defects are originally in the form of dangling bonds of silicon. Usually, the dangling bonds are

neutral, but they can be charged by trapping the carriers. If such defects are present at a high density in a polycrystalline silicon film, all of the carriers induced by field effect when a TFT is operated are entrapped by the defects. Therefore, no current flows between the source and drain electrodes. As a result, it is necessary to apply a  
5 higher gate voltage, which leads to the increase in threshold voltage. To prevent it, once the entire surface crystallization in the above-described laser crystallization process has been completed, the substrate is transferred with a vacuum robot into a plasma treatment chamber. Hydrogen, oxygen, or nitrogen gas is introduced into the chamber via a mass flow controller and plasma discharge is initiated over the entire  
10 surface of a sample with parallel flat RF electrodes. During this process, the gas pressure is adjusted to about 1 Torr, for example. Plasma can be also generated by inductively coupled RF discharge, ECR discharge, DC discharge, or ionization employing thermal electrodes produced by a hot filament. When a polycrystalline silicon film immediately after laser crystallization is subjected to hydrogen plasma  
15 treatment at a substrate temperature of 250°C for 5 to 300 s, the density of defects in the film can be reduced dramatically to about  $10^{16}$  ( $\text{cm}^{-2}\text{eV}^{-1}$ ) and a polycrystalline silicon film with excellent electric properties can be obtained.

[0029]

20 Since hydrogen has a very high diffusion rate in silicon films, if polycrystalline silicon with a film thickness, for example, of about 50 nm is processed, the sufficient processing time is about 160 s. Hydrogen has a small atomic radius and effective defect passivation to deep positions in the polycrystalline silicon film, that is, to the interface with the prime layer can be conducted within a short time. Depending on  
25 the substrate temperature, hydrogen plasma produces the effect of a silicon etching mode. In order to avoid it, the substrate temperature has to be maintained at a

temperature of about 100-400°C. Furthermore, the tact time of the process can be effectively shortened, for example, by conducting laser crystallization and then moving the substrate into a separate vacuum chamber with a vacuum robot arm and then conducting the above-described hydrogen, oxygen, and nitrogen plasma

5 treatment.

[0030]

For the reasons described above, hydrogen plasma is employed for reducing the number of defects. However, the number of defects can also be reduced by

10 conducting plasma treatment by oxygen plasma, nitrogen plasma, fluorine plasma, and the like.

[0031]

(4. Formation of First-stage Insulating Film Formation: FIG. 1 (c))

15 The above-described processes can improve quality of polycrystalline silicon films. Another important process is the formation of a high-quality MOS interface. In this process, oxygen atoms are smartly bonded to silicon atoms present on the polycrystalline silicon surface and the interface level density is reduced. Since about  $10^{15}$  ( $\text{cm}^{-2}$ ) bonds are present on the silicon film surface, it is important that

20 practically all of them form purely chemical bonds with  $\text{SiO}_2$ . In order to improve transistor characteristics of TFT, it is necessary to limit the interface level density, for example, to about  $10^{10}$  ( $\text{cm}^{-2}$ ). Thus, only about one defect is allowed for 100,000 silicon bonds and the following bonds have to be orderly bonded to oxygen atoms. In the conventional plasma CVD process, the interface level density could be controlled

25 only to  $10^{12}$  ( $\text{cm}^{-2}\text{eV}^{-1}$ ). In accordance with the present invention, in the process for forming a gate insulating film on a semiconductor layer, the treatment is conducted at

a substrate temperature of no higher than 100°C. In plasma CVD, SiH<sub>4</sub> gas is decomposed by active oxygen radicals present in plasma and SiO<sub>2</sub> is formed in a gas phase and deposited on the substrate. SiO<sub>2</sub> deposited in such highly reactive atmosphere can form chemical bonds with silicon on the semiconductor surface and

5 produce a good interface. However, because of active species of oxygen present in the film-forming atmosphere, oxidation of semiconductor surface proceeds simultaneously with the deposition of SiO<sub>2</sub>. Oxidation as referred herein is an effect proceeding at a level of no more than one atom level. If silicon is oxidized, volume is increased by a factor of 1.5 and local stress generation accompanies the formation

10 of oxidized Si – SiO<sub>2</sub> bonds. This is the main reason for the appearance of interface level. Thus, if the ratio of Si-SiO<sub>2</sub> bonds formed by oxidation increases with respect to the ratio at which good Si-SiO<sub>2</sub> bonds are formed by deposition of SiO<sub>2</sub>, eventually a MOS interface having a high interface level is formed. Quantitatively speaking, almost all of about  $10^{15}$  (cm<sup>-2</sup>) silicon bonds present on the interface form good

15 bonds by SiO<sub>2</sub> deposition. However, if Si-SiO<sub>2</sub> bonds whose number is no less than  $10^{10}$  (cm<sup>-2</sup>) among the above-mentioned bonds are formed by silicon oxidation, all of them become interface levels. Thus, even if oxidation occurs per one Si-SiO<sub>2</sub> bond in 100,000 bonds, that is, with a probability of 1 of  $10^5$ , interface levels are produced in an amount which cannot be ignored. Such interface formation mechanism obviously

20 occurs at the initial stage of film formation. Thus, the above-described oxidation process is initiated when SiO<sub>2</sub> deposition on semiconductor is started. The present invention discloses this interface formation mechanism and also discloses that the activation energy of the density of interface levels formed by the above-described oxidation is very high. In other words, the density of interface levels can be controlled

25 by substrate temperature. FIG. 4 presents experimental results on the substrate temperature during insulating film formation and relationship between the density of

interface levels  $Dit$  ( $\text{cm}^{-2}\text{eV}^{-1}$ ) and the time of thermal annealing in hydrogen atmosphere. Those results indicate that thermal annealing in a hydrogen atmosphere can reduce the respective number of interface levels, but this treatment fails to restore the bonds that has been oxidized. However, the probability of oxidation occurring on silicon surface can be dramatically reduced by decreasing the substrate temperature during film formation. It indicates that oxidation occurring at the interface strongly depends on the substrate temperature, that is, the oxidation occurs easier with the increase in substrate temperature. FIG. 4 demonstrates that the density of interface levels can be reduced to about  $1 \times 10^{11}$  ( $\text{cm}^{-2}\text{eV}^{-1}$ ) by decreasing the substrate temperature to less than  $100^\circ\text{C}$ . Furthermore, if the substrate temperature is made about  $100^\circ\text{C}$ , the appearance of OH bonds, which are byproducts of plasma CVD, in the insulating film can be inhibited. As a result, reliability of insulating film and flat-band voltage shift can be guaranteed, thereby providing conditions favorable for practical applications. Furthermore, film growing may also be conducted without substrate heating. With such method, the apparatus structure is simplified which is very beneficial in terms of production cost. Moreover, since the adjustment of substrate temperature is not required, the process throughput is high. Moreover, with such method, a good interface level density of  $8 \times 10^{10}$  ( $\text{cm}^{-2}\text{eV}^{-1}$ ) is provided. When film if formed by plasma CVD, heat is transferred from plasma to substrate and the substrate temperature rises. Therefore, an effective approach also comprises closely controlling the substrate to a low temperature. Thus, an even better interface level density can be obtained by cooling the substrate to a temperature about or below the room temperature. As shown in FIG. 4, the interface level density of  $3 \times (10^{10}$   $\text{cm}^{-2}\text{eV}^{-1})$  can be decreased to  $1 \times 10^{10}$  ( $\text{cm}^{-2}\text{eV}^{-1}$ ) by cooling the substrate to a temperature of  $-50^\circ\text{C}$ . Those values of interface level density are the same as the values of interface level density obtained when an insulating film was formed by

thermal oxidation. Thus, the decrease of substrate temperature during insulating film formation makes it possible to form an excellent MOS interface even at a low temperature. The utilization of such ultrahigh-quality MOS interface allows the threshold voltage of field-effect transistor to be decreased to about 1 V. As a result, a 5 circuit with an ultralow power consumption can be realized.

[0032]

The above-described interface control technology is especially important in forming an insulating film by plasma. This is because a large number of oxygen active species are produced under a lower pressure. Thus, the control of oxidation process occurring with a slight probability on a semiconductor surface with those oxygen active species is essential for the formation of MOS interface using plasma. Moreover, in plasma CVD using microwave discharge, the effect of interface level density reduction is significant. This is because the microwave discharge plasma has 10 an advantage of a high plasma density, but since it is generated under a relatively low pressure of about  $10^{-3}$  (Torr), the mean free path of electrons in the plasma is long and a higher-order dissociation is promoted. Thus, atomic oxygen and oxygen radicals, rather than oxygen molecule radicals, mainly participate in the reaction and they are very active with respect to interface oxidation. Therefore, in the formation of 15 an insulating film by using microwave discharge plasma, the interface level density can be dramatically decreased by decreasing the substrate temperature.

[0033]

A specific process, for example, comprises conducting continuous plasma 25 treatment in vacuum of a polycrystalline silicon film formed by laser crystallization and then vacuum transporting it into an insulating film formation chamber, without

disrupting the vacuum state. The substrate temperature is adjusted to less than 100°C inside the vacuum chamber and evacuation is conducted till the background vacuum degree reaches  $10^{-6}$  (Torr). In such state, oxygen gas and silane gas ( $\text{SiH}_4$ ) are fed into the vacuum chamber. A method of diluting with He gas for discharge 5 stabilization may also be employed. Typically, the oxygen flow rate is no less than five times that of silane gas. In this state, plasma discharge is initiated and a  $\text{SiO}_2$  film (insulating film) 105 is formed. Examples of the discharge mode include flat and parallel RF discharge, ICP discharge, ECR discharge and the like. An RF power source, VHF, UHF power source, and microwave source can be used as a power 10 source. The above-described process is a first-stage insulating film formation process.

[0034]

(5. Annealing Process)

15 In accordance with the present invention, upon completion of the insulating film formation process, the substrate is removed from the vacuum apparatus and heat treated in an atmosphere comprising water at a substrate temperature of 100°C or more. The insulating film 105 formed at a low substrate temperature in the above-described process contains a large number of Si-OH bonds which are the 20 reaction byproducts and have a poor bulk insulating characteristic. Accordingly, this process is conducted to improve this characteristics. In particular, defects located in the insulating film present in the vicinity of semiconductor surface and MOS interface allowing for entrapment of carriers also affect the MOS interface levels. FIG. 5 shows a CV characteristic directly after the insulating film formation and after the 25 above-described annealing process has been conducted.

[0035]

If a large number of OH bonds are present in the vicinity of insulating film interface, they produce an adverse effect on interface characteristics. Furthermore, the breakdown voltage of the bulk insulating film is decreased. However, if heat treatment is conducted in a steam atmosphere at a temperature of no less than 100°C, the number of those Si-OH bonds can be reduced dramatically. FIG. 5 clearly shows the significance of this effect. As a result, the present invention can guarantee a dramatic reduction in interface level density, a high breakdown voltage, and good reliability.

10

[0036]

(6. Element Separation Process: FIG. 1 (d))

A MOS structure of extremely high quality is formed by the above-described continuous vacuum process comprising laser crystallization, plasma treatment, and MOS interface formation. Then, element separation is conducted in order to insulate electrically the TFT elements from each other. For this purpose, as shown in FIG 1 (d), the insulating film and polycrystalline silicon layer are etched continuously. For example, a pattern is formed on the insulating film 105 by photolithography and then  $\text{SiO}_2$ , is etched by wet or dry etching. The polycrystalline silicon layer is dry etched thereafter. Since in this process two layers,  $\text{SiO}_2$  and poly-Si film, are etched, measures should be taken to avoid the formation of defects on edges after etching.

20 [0037]

(7. Second-stage Gate Insulating Film Formation: FIG. 1 (e))

Once the island-like  $\text{SiO}_2$  and polycrystalline silicon layer have been formed, a gate insulating film 106 is formed over the entire substrate surface. Examples of

methods suitable for the formation of gate insulating film include ECR plasma CVD method, flat and parallel RF discharge plasma CVD method, and the like.

Furthermore, the insulating film may also be formed by SiO deposition among the oxygen radicals for the second time. However, if the insulating film formed in the

5 second stage does not have good step coverage, an electric short circuit can occur in the step portions, causing decrease in breakdown voltage. For this reason, film forming method providing for excellent step coverage, for example, plasma CVD using TEOS and oxygen as starting material gases is effective. Furthermore, since the insulating film formed in the first stage is formed at a low temperature, the

10 breakdown voltage tends to decrease. However, with the two-stage insulating film formation method disclosed by the present invention, the breakdown voltage of the entire insulating film can be increased by forming the insulating film at a substrate temperature of no less than 100°C as a second stage process. FIG. 6 compares the results obtained in studying the breakdown voltage of an insulating film (single layer)

15 when only the first-stage film was formed (substrate temperature 100°C) and those obtained in studying an insulating film with a two-layer structure (double layer) after the formation of a second-stage insulating film (substrate temperature 300°C, TEOS + O<sub>2</sub>). Those results clearly show that the second-stage insulating film formation method disclosed by the present invention makes it possible to improve the

20 breakdown voltage of the insulating film to a level of about 7 (MV/cm) sufficient for practical applications. Thus, using different insulating film forming methods for MOS interface formation and bulk insulating film formation makes it possible to realize both the excellent MOS interface characteristics and the bulk insulating film characteristics, which was impossible with the conventional low-temperature

25 process.

[0038]

(8. Subsequent Processes)

Then, as shown in FIG. 1 (e), a thin film serving as a gate electrode 107 is deposited by a PVD method or CVD method. The material of gate electrode  
5 preferably has a low electric resistance and good stability against thermal processing at a temperature of about 350°C; for example, metals with a high melting point, such as tantalum, tungsten, chromium, and the like are suitable for this purpose. Furthermore, the thickness of the gate electrode should be about 700 nm in order to prevent hydrogen channeling when a source and a drain are formed by ion doping.  
10 Among those metals with a high melting point, for example, tantalum is appropriate as a material demonstrating no cracking induced by stresses even when the film is grown to a thickness of 700 nm. Patterning is conducted after the deposition of thin film serving as a gate electrode and then source and drain regions 108, 109 are formed by conducting ion implantation of dopants into the semiconductor film.

15

[0039]

In this process, the gate electrode serves as a mask for ion implantation. Therefore, a self-aligned structure is obtained in which a channel is formed only below the gate electrode. Two types of methods are suitable for ion implantation:  
20 anion doping method in which hydrogen and a hydride of the dopant element are implanted with a mass-inseparable ion implantation apparatus and an ion bombardment method in which only the desired dopant element is implanted by using a mass-separable ion implantation apparatus. Hydrides of the dopant elements such as phosphine ( $\text{PH}_3$ ) or diborane ( $\text{B}_2\text{H}_6$ ) diluted with hydrogen to a concentration  
25 from about 0.1% to about 10% are used as the starting materials for ion doping. With the ion bombardment method, hydrogen ions (protons or hydrogen molecule ions)

are implanted after the desired dopant elements have been implanted. As described above, in order to maintain stability of MOS interface or gate insulating film, the substrate temperature is preferably no more than 350°C in ion doping method, ion bombardment method, or ion implantation method. On the other hand, in order to

5 conduct with high stability the activation of implanted dopants at a low temperature of no higher than 350°C (in the present specification, this process is referred to as low-temperature activation), the substrate temperature during ion implantation is preferably no less than 200°C. Furthermore, the substrate temperature during ion implantation should be no less than 250°C in order to activate reliably at a low

10 temperature the dopant ions that have been implanted to a low concentration so as to produce an LDD structure or to conduct channel doping to adjust the threshold voltage of transistor. Thus, if ion implantation is conducted in a state with a high substrate temperature, recrystallization simultaneously proceeds during crystal fracture accompanying ion implantation into a semiconductor film. As a result,

15 amorphization of the ion implantation region can be prevented. Thus, the region where ion implantation has been conducted remains crystalline even after ion implantation and subsequent activation of implanted ions can be conducted even at a low activation temperature of no more than about 350°C. When CMOS TFT is fabricated, NMOS and PMOS are alternately covered with a mask made from an

20 appropriate mask material, such as polyimide resin, for respective ion implantation by the above-described method.

[0040]

Laser activation by irradiation, for example, with an excimer laser is an

25 effective method for dopant activation. With such method the doped polycrystalline silicon of the source and drain regions is melted and solidified and dopants are

activated by laser irradiation via the insulating film.

[0041]

Then, as shown in FIG.1 (g), the fabrication of a thin-film transistor is

- 5 completed by opening a contact hole above the source and drain and forming source and drain lead-out electrodes 110, 111 and wirings, for example, by PVD or CVD method.

[0042]

10 [Embodiments]

A preferred embodiment of the present invention will be described below with reference to FIG. 1. Substrate and protective underlayer were according to the above explanation. In one example, an alkali-free glass for general applications having a rectangular shape of 300 mm x 300 mm was used as substrate. First, a protective

- 15 underlayer 102 which is an insulating substance was formed on substrate 101. Here, a silicon oxide film having a thickness of about 200 nm was deposited by

ECR-PECVD method at a substrate temperature of 150°C. Then, a semiconductor layer 103 such as pure silicon film serving as an active layer of a thin-film transistor

was deposited. The thickness of the semiconductor film was about 50 nm. In this

- 20 embodiment, an amorphous silicon film 103 was deposited at a deposition

temperature of 425°C by using high-vacuum LPCVD apparatus and feeding disilane

( $\text{Si}_2\text{H}_6$ ) as a starting material gas at 200 SCCM. First, a plurality of substrates (for

example, 17 substrates) were disposed, so that the surface side thereof was facing downward, inside a reaction chamber of a high-vacuum LPCVD with a reaction

- 25 chamber temperature of 250°C. Then, a turbomolecular pump was started. Once the rotation rate of the turbomolecular pump has reached the rated level, the

temperature inside the reaction chamber was raised from 250°C to a deposition temperature of 425°C within about 1 hour. In the initial 10 min since the beginning of temperature increase, absolutely no gas was introduced into the reaction chamber and the temperature was raised in vacuum. Then, heating was continued while

5 nitrogen gas with a purity of no less than 99.9999% was fed at 300 SCCM. The average pressure inside the reaction chamber in this process was  $3.0 \times 10^{-3}$  Torr. Once the deposition temperature has been reached, disilane ( $\text{Si}_2\text{H}_6$ ) which was a starting material was fed at 200 SCCM and at the same time helium (He) with a purity of no less than 99.9999% was fed at 1000 SCCM for dilution. The pressure

10 inside the reaction chamber immediately after the beginning of deposition was about 0.85 Torr. In the course of deposition, the pressure inside the reaction chamber gradually increased and just before completion of deposition it was about 1.25 Torr. In silicon film 103 deposited in a similar manner, the variation of thickness was within  $\pm 5\%$  within a 286-mm square region, excluding about 7 mm on the periphery of

15 substrate.

#### [0043]

Then, prior to laser crystallization, the amorphous silicon film was immersed in a hydrofluoric acid solution and the natural oxidation film present on the

20 semiconductor layer 103 was etched out. Typically the exposed surface of a silicon film is extremely unstable and easily reacts with an atmosphere where the silicon thin film is maintained. Therefore, as a pretreatment conducted prior to laser irradiation, it is necessary not only to remove the natural oxidation film, but also to stabilize the exposed silicon film surface. For this purpose, treatment with a hydrofluoric acid

25 solution is preferably conducted. In the present embodiment, the mixing ratio of hydrofluoric acid and pure water was 1 : 30. Upon immersion for about 20 to 30

minutes of the semiconductor into such hydrofluoric acid solution, washing with pure waster was immediately conducted for 10-20 min. Pure water was thereafter removed with a spinner. As a result, the silicon film had a stabilized surface terminated with hydrogen atoms.

5

[0044]

Laser beam irradiation was then conducted. In the present embodiment, irradiation was conducted with an excimer laser (wavelength : 308 nm) of xenon chloride (XeCl).The intensity half-width of laser pulse (half-width with respect to time) was 25 ns. The substrate was set in a laser crystallization chamber, followed by evacuation. Upon evacuation, the substrate temperature was raised to 250°C. A single laser irradiated area was a square with 10 mm on a side. The energy density in the irradiation area was 160 mJ/cm<sup>2</sup>. The irradiation was repeated (see FIG. 2), while shifting the laser beam so as to obtain a 90% overlapping (in other words, shifting by 1 mm per each irradiation cycle). As a result, amorphous silicon was crystallized on the entire substrate with 300 mm on a side. Second laser irradiation was conducted by using the same irradiation method. In the second laser irradiation, the energy density was 180 mJ/cm<sup>2</sup>. The operations were repeated third and fourth time by raising the irradiation energy density by about 20 mJ/cm<sup>2</sup> each time, and finally laser irradiation was completed by conducting irradiation at an energy density of 440 mJ/cm<sup>2</sup>. If irradiation is conducted at a high energy exceeding the irradiation laser energy of 450 mJ/cm<sup>2</sup>, refining of p-Si grains is initiated. For this reason, irradiation with the energy above this level was avoided.

25

[0045]

The substrate was then transported into a plasma treatment chambers, while

being maintained under vacuum, and hydrogen gas was introduced into the chamber. In this example, hydrogen with a purity of 99.999% was introduced from a mass flow controller and the pressure inside the chamber was adjusted to 1 Torr. In this state, a discharge was conducted by applying 13.56 MHz RF to parallel flat electrodes, and defects present in laser crystallized poly-Si film were terminated by hydrogen. The substrate temperature was 250°C and the input RF power was 3 W/cm<sup>2</sup>. Since hydrogen can diffuse in the film within a rather short time, the defects present at a large depth in the polycrystalline silicon film and at the interface with the prime layer were effectively terminated by treatment conducted for 160 s.

10

[0046]

Substrate 100 was then transported into an insulating film formation chamber, while being maintained under vacuum. Upon completion of substrate transportation, the chamber was evacuated to a degree of vacuum of 10<sup>-6</sup> Torr. The 15 substrate was cooled herein to a temperature of -100°C.

[0047]

Within this period, silane gas and oxygen gas were introduced into the chamber at a flow rate ratio of 1 : 6 and the pressure inside the chamber was 20 adjusted to 2 x 10<sup>-3</sup> Torr. If the substrate temperature is stable, ECR discharge is induced and the formation of insulating film is initiated. The input microwave power was 1 kW, and microwaves were introduced from an inlet window parallel to magnetic force lines. An ECR point is in a position at a distance of 20 cm from the inlet window. The film growth was conducted at a rate of 100 nm/min. As a result, a 25 first-layer gate insulating film 105 having a thickness of 30 nm was formed.

[0048]

The substrate was then removed from the vacuum chamber and set into a saturated steam atmosphere at a temperature of 330°C, where heat treatment was conducted for 90 min. The polycrystalline silicon layer and first-layer insulating film  
5 were then continuously etched. A second-layer insulating film 106 was then deposited to a thickness of 70 nm at a substrate temperature of 350°C by a flat and parallel RF discharge PECVD method. A gaseous mixture of TEOS (Si-(O-CH<sub>2</sub>-CH<sub>3</sub>)<sub>4</sub>) and oxygen (O<sub>2</sub>) was used as a starting gas. A thin film serving as a gate electrode 107 was then deposited by a PVD method or CVD method. Usually,  
10 a gate electrode and gate wiring are fabricated from the same material in the same process. Therefore, the material thereof preferably has a low electric resistance and good stability with respect to heat treatment at a temperature of about 350°C. In the present embodiment, a tantalum thin film with a thickness of 600 nm was formed by sputtering. The substrate temperature during the tantalum thin film formation was  
15 180°C and argon gas containing 6.7% nitrogen was used as a sputtering gas. Similarly formed tantalum thin film had an α crystal structure and its specific resistance was about 40 μΩcm. Upon deposition of the thin film serving as a gate electrode, patterning was conducted and then dopant ion implantation into the semiconductor film was conducted to form source and drain regions 108, 109 and  
20 channel region. Since in this process the gate electrode 107 served as a mask for ion implantation, a self-aligned structure was obtained in which the channel was formed only below the gate electrode. Hydrides of the dopant elements such as phosphine (PH<sub>3</sub>) or diborane (B<sub>2</sub>H<sub>6</sub>) diluted with hydrogen to a concentration from about 0.1% to about 10% were used as starting materials for ion doping. In the  
25 present embodiment, with an object of forming an NMOS structure, an ion doping apparatus was used and phosphine (PH<sub>3</sub>) diluted with hydrogen to a concentration of

5% was implanted at an accelerating voltage of 100 keV. The total ion implantation ratio, including PH<sub>3</sub><sup>+</sup> and H<sub>2</sub><sup>+</sup> ions was 1 × 10<sup>16</sup> cm<sup>-2</sup>.

[0049]

5       The formation of a thin-film transistor was completed by opening a contact hole above the source and drain and forming source and drain lead-out electrodes 110, 111 and wiring by PVD or CVD method.

[0050]

10      The conventional technology provided no effective method for forming high-quality MOS interfaces. However, using the method for the fabrication of a field-effect transistor in accordance with the present invention as described above makes it possible to form a MOS interface of a very high quality. As a result, a field-effect transistor with high mobility and low threshold voltage can be fabricated 15     and a circuit with an ultralow power consumption can be realized.

[Brief Description of the Drawings]

[Fig.1]

20      A process cross-sectional view illustrating the method for the manufacture of a field-effect transistor in accordance with the present invention.

[Fig.2]

A diagram illustrating a method for laser beam irradiation during laser crystallization.

[Fig. 3]

A diagram illustrating a method for laser beam irradiation during laser crystallization.

5 [Fig.4]

A diagram illustrating the relationship between the interface level density of MOS interface formed in accordance with the present invention and the substrate temperature.

10 [Fig.5]

A diagram illustrating the high-frequency C-V characteristic of MOS structure fabricated by the process for forming a MOS interface in accordance with the present invention.

15 [Fig.6]

A diagram illustrating the breakdown voltage characteristic of a MOS structure fabricated by the two-stage insulating film formation process in accordance with the present invention and a MOS structure formed of a single layer.

20 [Description of Reference Numerals]

101 substrate

102 protective underlayer

103 semiconductor layer

104 laser beam

25 105 first-layer gate insulating film

106 second-layer gate insulating film

107 gate electrode  
108 source  
109 drain  
110 source lead-out electrode  
5 111 drain lead-out electrode  
201 laser irradiation region  
203 X direction shift  
204 Y direction shift  
301 line-like laser beam

10

[Document Name] Drawings

[Fig.1]

[Fig.2]

[Fig.3]

15 [Fig.4]

[Fig.5]

[Fig.6]

[Document Name]

Abstract

[Summary]

[Object] An object of the present invention is to realize excellent MOS interface characteristics and bulk insulating film characteristics by a low-temperature  
5 process.

[Solving Means] A first-stage gate insulating film forming process (c) is conducted at no higher than 100°C, and a second-stage gate insulating film forming process (e) is conducted at no less than 100°C after the formation of the first-stage gate insulating film.

10 [Selected Drawing] Fig. 1